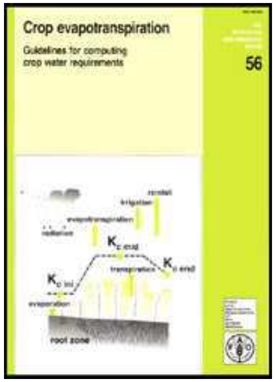
Dual Crop Coefficient: SimComponent Evaluation and Documentation Review

LAP Colloquium

Murilo Vianna

Mar-2022



Goal

- Review and evaluate the dual crop coefficient method implemented in SIMPLACE

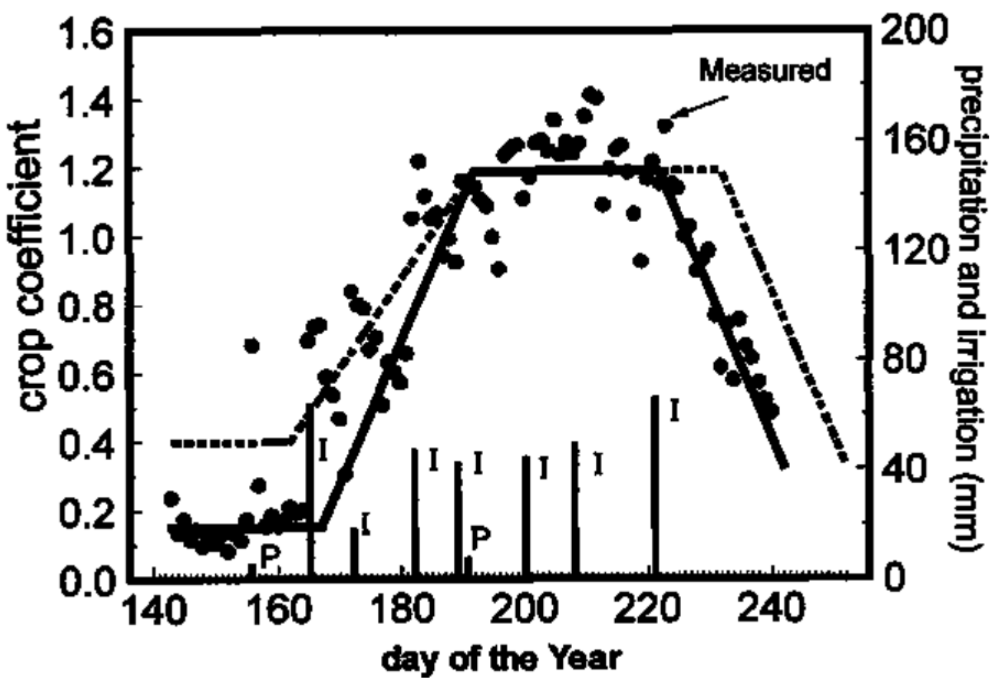
- Update SimComponent Documentation
  (https://simplace.net/doc/simplace_modules/)

net.simplace.sim.components.evapotran.fao56.

CropEvapoTranspirationDualCoeff

Chapter 7 - ET_c - Dual crop coefficient ($K_c = K_{cb} + K_e$)

$$ET_c = (K_{cb} + K_e)\, ET_o$$

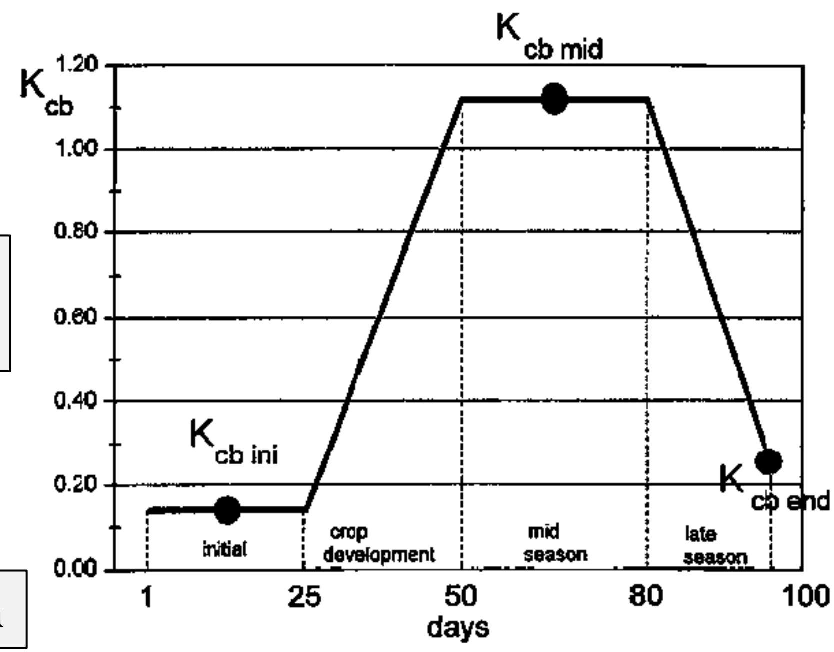


Allen et al. (1998). "Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements-FAO Irrigation and Drainage Paper 56." Fao. Freely available at: https://www.fao.org/3/x0490e/x0490e00.htm

Chapter 7 - ET_c - Dual crop coefficient ($K_c = K_{cb} + K_e$)

Required information for daily calculations:

- Weather data:
  - Srad, Tmax, Tmin, Prec, RelHum, Wind → ETo, Atm Corrections
- FAO crop development stages + DAP:
  - 1: initial, 2: crop development, 3: mid-season, 4: late season
- Kcb coefficients by stage:
  - Kcb(ini), Kcb(mid), Kcb(end)
- Canopy Height → Soil Cover Frac, Atm Corrections
  - mid-stage and daily
- Topsoil water holding capacity
  - WP, FC, Z(evap) → Soil evaporation



Chapter 7 - ET_c - Dual crop coefficient ($K_c = K_{cb} + K_e$)

Calculation steps:

a) Determine ETo

TABLE 11. Lengths of crop development stages* for various planting periods and climatic regions (days)

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
i. Cereals							
Barley/Oats/Wheat	15	25	50	30	120	November	Central India
	20	25	60	30	135	March/Apr	35-45 °L
	15	30	65	40	150	July	East Africa
	40	30	40	20	130	Apr	
	40	60	60	40	200	Nov	
	20	50	60	30	160	Dec	Calif. Desert, USA

b) Determine 4-stage development lengths
- Length in days

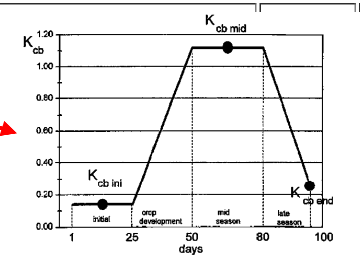
c) Calculate basal crop coefficient (Kcb)

TABLE 17. Basal crop coefficients, K_c, for non stressed, well-managed crops in subhumid climates ($RH_{min} \approx 45\%$, $u_2 \approx 2$ m/s) for use with the FAO Penman-Monteith ET_o.

Crop	$K_{cb\,ini}$[1]	$K_{cb\,mid}$	$K_{cb\,end}$
i. Cereals	**0.15**	**1.10**	**0.25**
Barley		1.10	0.15
Oats		1.10	0.15
Spring Wheat		1.10	0.15-0.3[10]
Winter Wheat	0.15-0.5[11]	1.10	0.15-0.3[10]

Atmospheric Correction *"Characteristic" RHmin, u2, h*

$$K_{cb} = K_{cb(Tab)} + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3}$$



d) Calculate soil evaporation coefficient (Ke)

$$K_e = K_r\,(K_{c\,max} - K_{cb}) \le f_{ew}\,K_{c\,max}$$

Soil Water Balance

Atmospheric Correction

$$K_{c\,max} = \max\left(\left\{1.2 + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3}\right\}, \{K_{cb} + 0.05\}\right)$$

$$f_{ew} = \min(1 - f_c,\ f_w)$$

$$f_c = \left(\frac{K_{cb} - K_{c\,min}}{K_{c\,max} - K_{c\,min}}\right)^{(1+0.5h)}$$

Implementation in simplace
modelling framework

Goal:

Fractionate the potential evapotranspiration (ETp) between crop transpiration (Tp) soil evaporation (Ep): *ETp = Ep + Tp*

Main Assumption:

Crop DVS and LAI as proxy for the FAO's scale of crop development:

- When DVS < 0.001 (before emergence):

  Kcb = Kcb_ini (typically = 0)

- When DVS >= 0.001 (after emergence):

  *Kcb = Kcb_ini + (Kcb_full – Kcb_ini) * (1-exp[-k * LAI])*

Implementation in simplace modelling framework

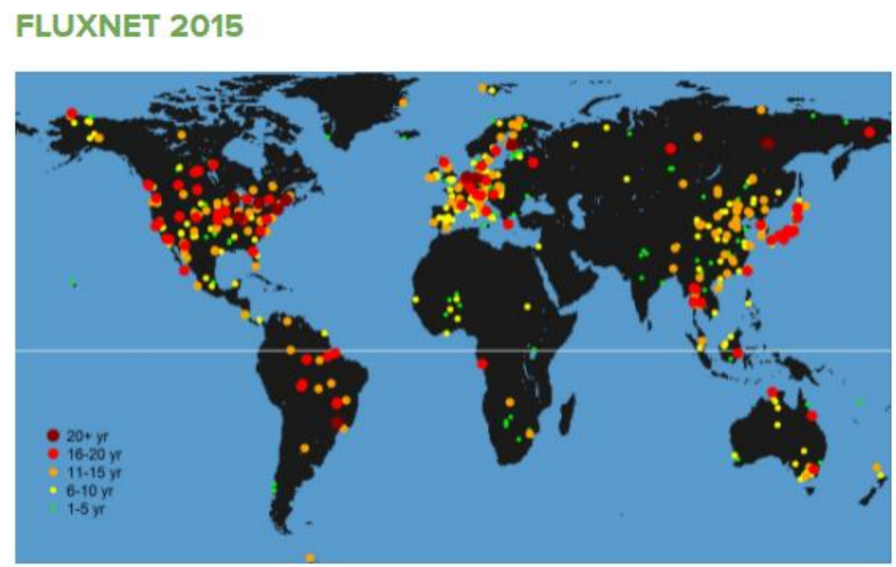
Component Variables

Content Type	Name	Description	Data Type	Unit	Min Value	Max Value	Default Value
constant	cCharacteristicMeanRelHumidity	region's characteristic mean daily min relative humidity for mid/late growth season	DOUBLE	%	0.0	100.0	45.0
constant	cCharacteristicWindspeed	region's characteristic wind speed at 2m during the mid growing season m s-1	DOUBLE	m/s	0.0	-	2.0
constant	cCropHeight	average crop height during mid/late season	DOUBLE	m	0.0	5.0	0.0
constant	cK	canopy light extinction factor	DOUBLE	1	0.0	1.0	0.7
constant	cKcMin	min Kc for dry bare soil with no ground cover	DOUBLE	1	0.0	2.0	0.15
constant	cKcbIni	nominal Kcb value during initial growth stage	DOUBLE	1	0.0	2.0	0.0
constant	cKcbMid	nominal peak Kcb value obtained during mid season growth stage	DOUBLE	1	0.0	2.0	1.0
constant	cWettedSoilFraction	fraction of soil surface wetted by rain or irrigation	DOUBLE	1	0.0	1.0	1.0
constant	iK_r	evaporation reduction coefficient dependent on the cumulative depth of water depleted (evaporated) from the topsoil	DOUBLE	1	0.0	1.0	1.0
constant	iK_s	Crop water stress factor (optional)	DOUBLE	1	0.0	1.0	1.0
input	iDVS	daily value of development stage	DOUBLE	1	0.0	2.5	0.0
input	iDoHarvest	harvesting	BOOLEAN	1	-	-	false
input	iDoSow	sowing	BOOLEAN	1	-	-	false
input	iLAI	daily estimated leaf area index	DOUBLE	1	0.0	20.0	0.0
input	iReferenceCropEvapotranspiration	reference crop evapotranspiration (ET0)	DOUBLE	mm	0.0	20.0	0.0
out	ActualTranspiration	adjusted rate of transpiration from the soil under - when K_s is set -water stress conditions	DOUBLE	mm/d	0.0	20.0	-
out	ETC	crop ET under standard conditions (no water, nutrient, weed, pest or disease limitations to growth)	DOUBLE	mm/d	0.0	20.0	-
out	ETCUpper	upper limit (no evaporation reduction K_r) of crop ET under standard (or - when K_s is set - water stress) conditions (no nutrient, weed, pest or disease limitations to growth)	DOUBLE	mm/d	0.0	20.0	-
		adjusted crop ET under - when K_s is set - water					

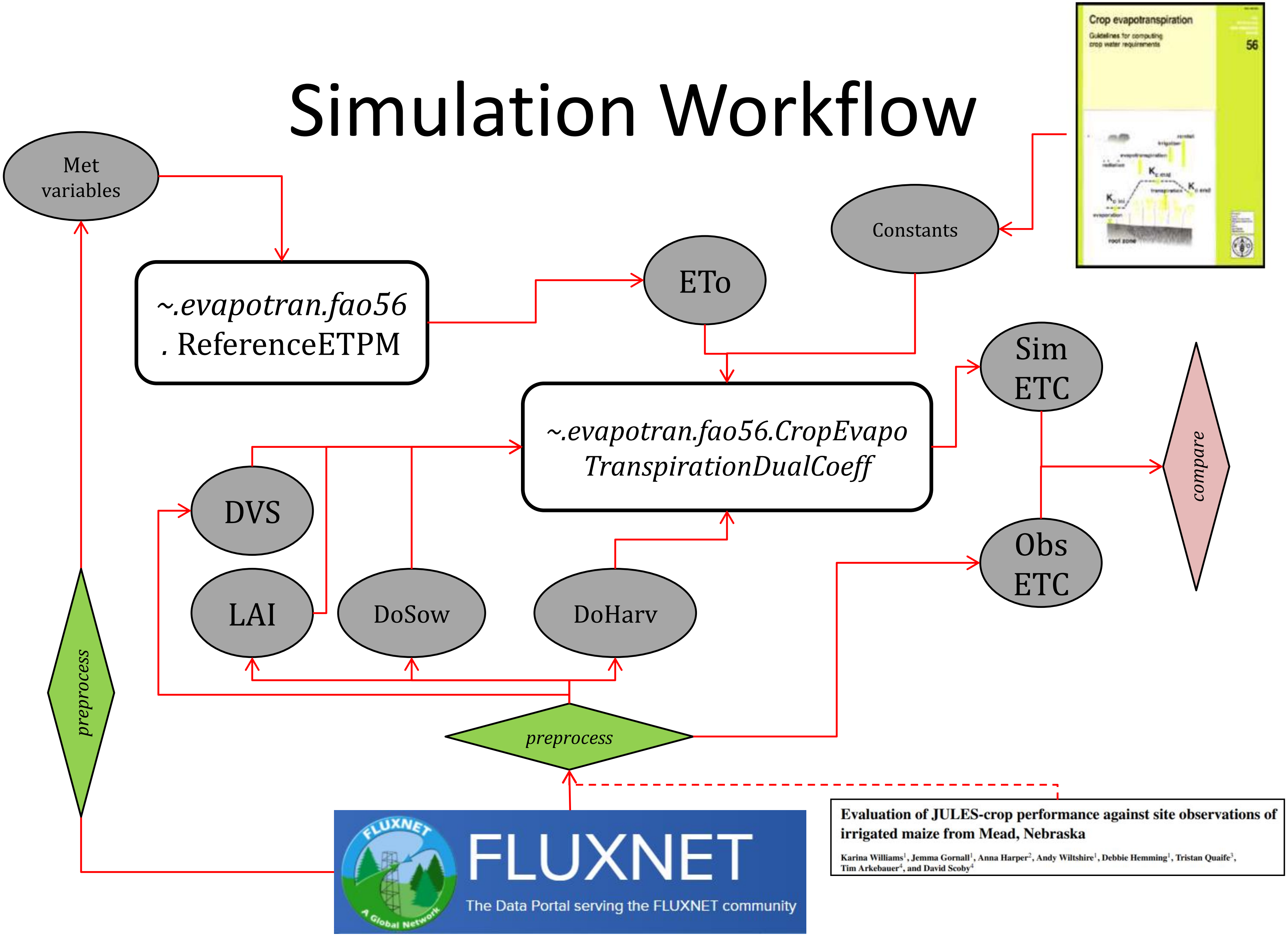
Testing against ETc data

Two sites in Nebraska (USA) with maize crop under fully irrigated conditions

- Fluxnet sites US-Ne1 and US-Ne2
- 17 crop seasons
- Latent heat flux
- Meteorological variables
- LAI and h measurements
- Williams et al. (2017)



Simulation Workflow



Preprocess

DVS, DoSow and DoHarvest

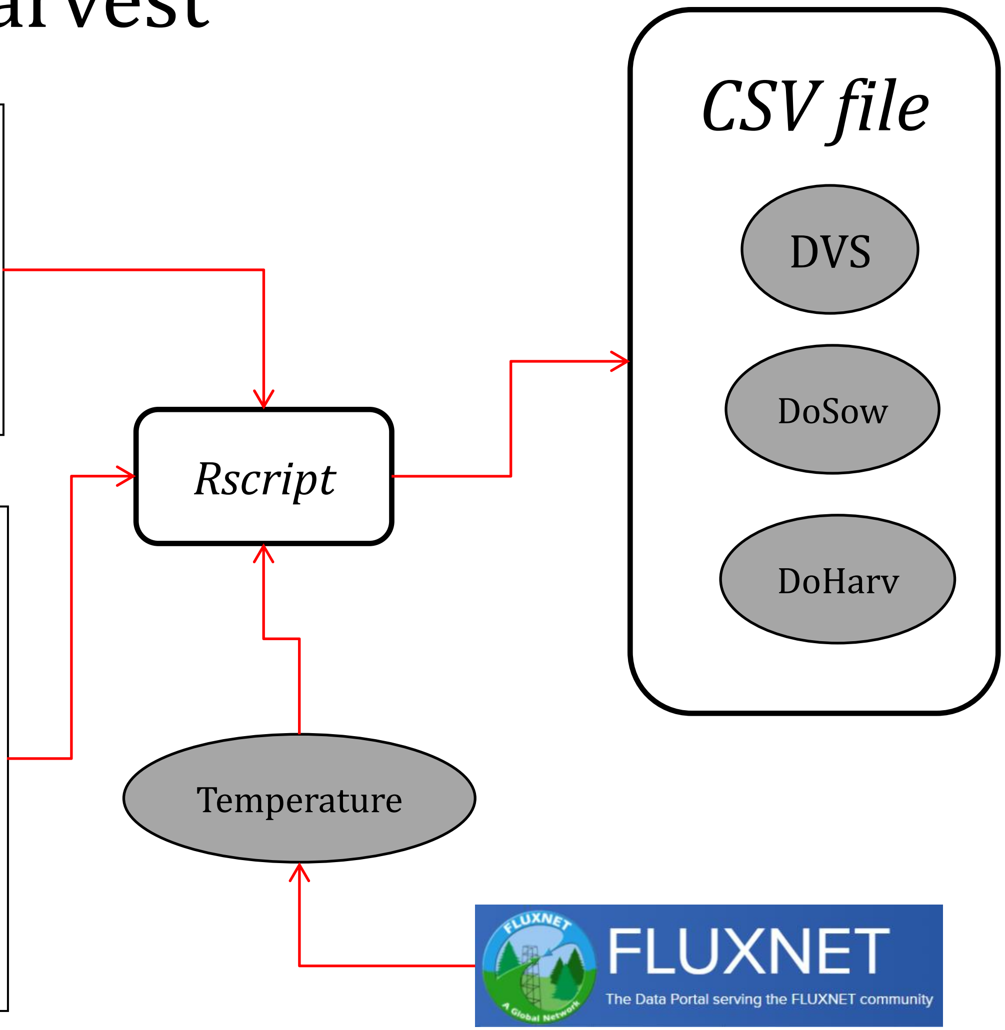
Table 3. Values of the crop-specific JULES parameters used to represent maize. Units are given in brackets; (–) denotes dimensionless. These parameters are all specified in the `JULES_CROPPARM` namelist. Values of the crop-specific JULES parameters used to represent maize. Units are given in brackets; (–) denotes dimensionless. These parameters are all specified in the `JULES_CROPPARM` namelist.

	JULES notation	Osborne et al. (2015)	This study	Remarks
T_b	t_bse_io	281.15	281.15	Base temperature parameter in thermal time calculation (K). See Sect. 2.3.1.
T_o	t_opt_io	303.15	303.15	Optimum temperature parameter in thermal time calculation (K). See Sect. 2.3.1.
T_m	t_max_io	315.15	315.15	Maximum temperature parameter in thermal time calculation (K). See Sect. 2.3.1.
TT_{emr}	tt_emr_io	80	Table 5	Thermal time between sowing and emergence (degree days). See Sect. 2.3.1.
TT_{veg}	tt_veg	Osborne et al. (2015) fig.3	Table 5	Thermal time between emergence and flowering (degree days). See Sect. 2.3.1.
TT_{rep}	tt_rep	Osborne et al. (2015) Fig. 3	Table 5	Thermal time between flowering and harvest (degree days). See Sect. 2.3.1.

K. Williams et al.: JULES-crop performance for irrigated maize 1301

Table 5. Thermal times in degree days based on crop dates recorded at the Mead FLUXNET sites, combined with hourly observed temperatures.

Year	Sowing DOY	Sowing–emergence	Emergence–flowering	Flowering–maturity	Flowering–harvest	Sowing–harvest
US-Ne1						
2002	130	85.55	–	–	–	2011
2003	135	59.71	868.6	–	1001	1938
2004	125	113.0	844.1	784.7	977.0	1945
2005	124	107.3	923.2	869.4	1083	2129
2006	124	59.32	819.8	883.6	1086	1973
2007	121	84.84	865.7	932.6	1331	2281
2008	120	64.48	888.4	967.3	1138	2102
2009	110	89.44	903.6	836.2	959.3	1961
2010	109	84.62	808.3	935.5	1011	1917
2011	137	69.71	819.9	827.1	980.1	1885
2012	114	58.90	718.3	961.6	1275	2062
US-Ne2						
2003	134	53.41	830.0	–	1005	1887
2005	122	95.51	822.8	923.9	1218	2153
2007	121	96.33	849.6	932.3	1300	2254
2009	111	93.63	853.0	801.6	884.72	1837
2010	110	108.2	846.2	–	908.4	1874
2011	137	67.10	792.0	864.3	1039	1912
2012	115	55.92	694.1	993.0	1282	2042

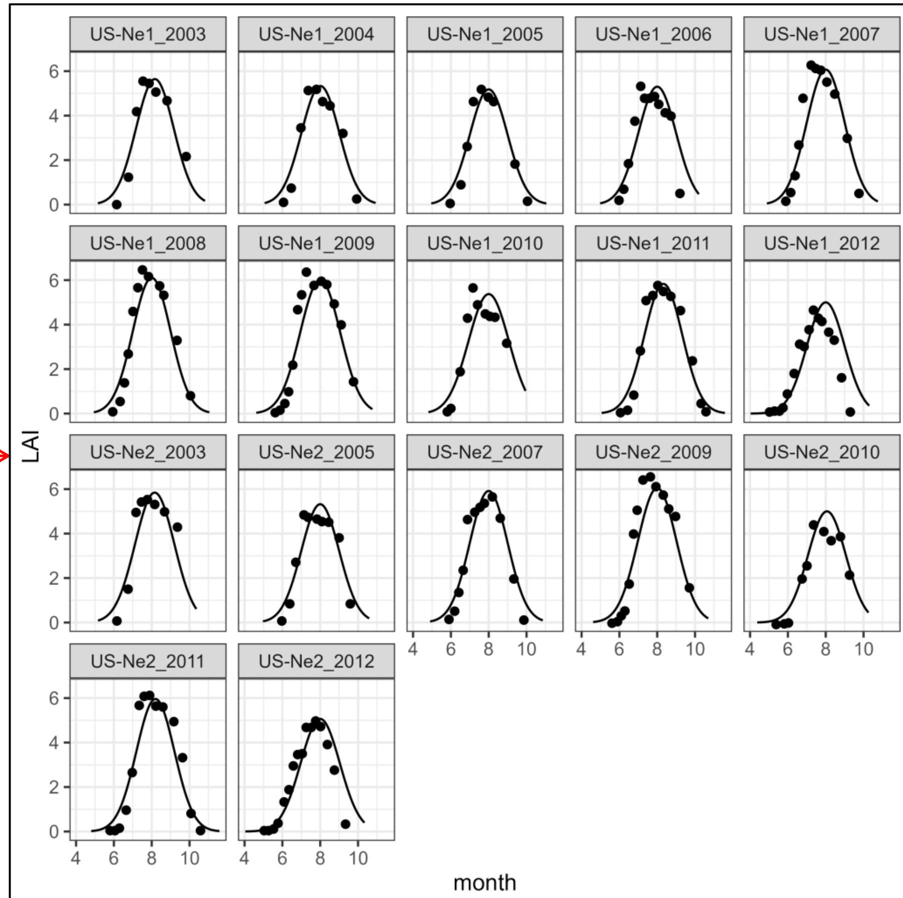


Preprocess

DAILY LAI

GAUSS ~ DOY

Rscript



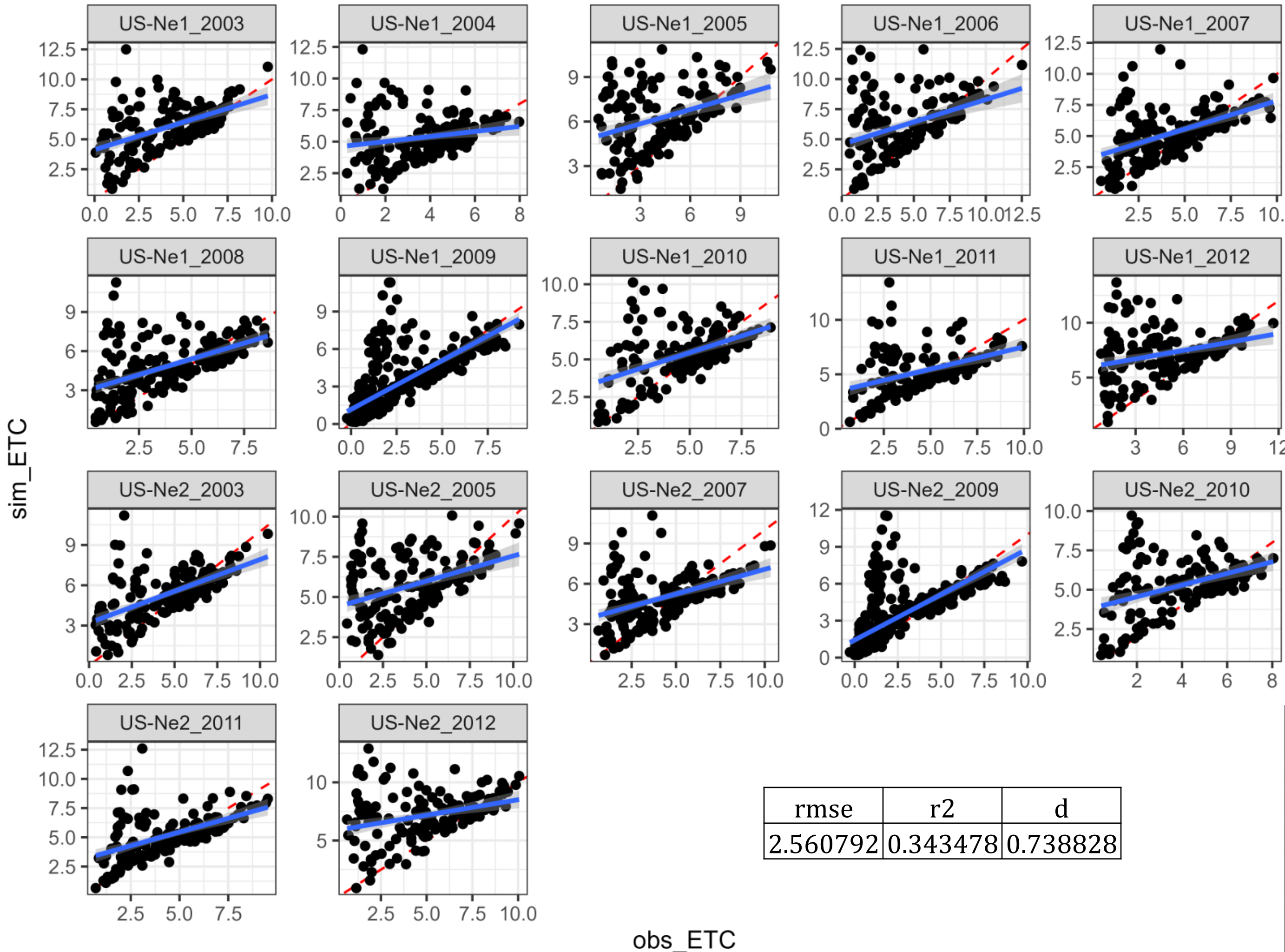
CSV file

LAI

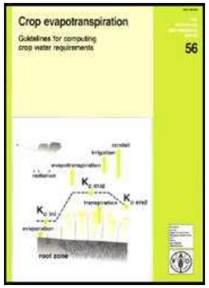
FLUXNET

The Data Portal serving the FLUXNET community

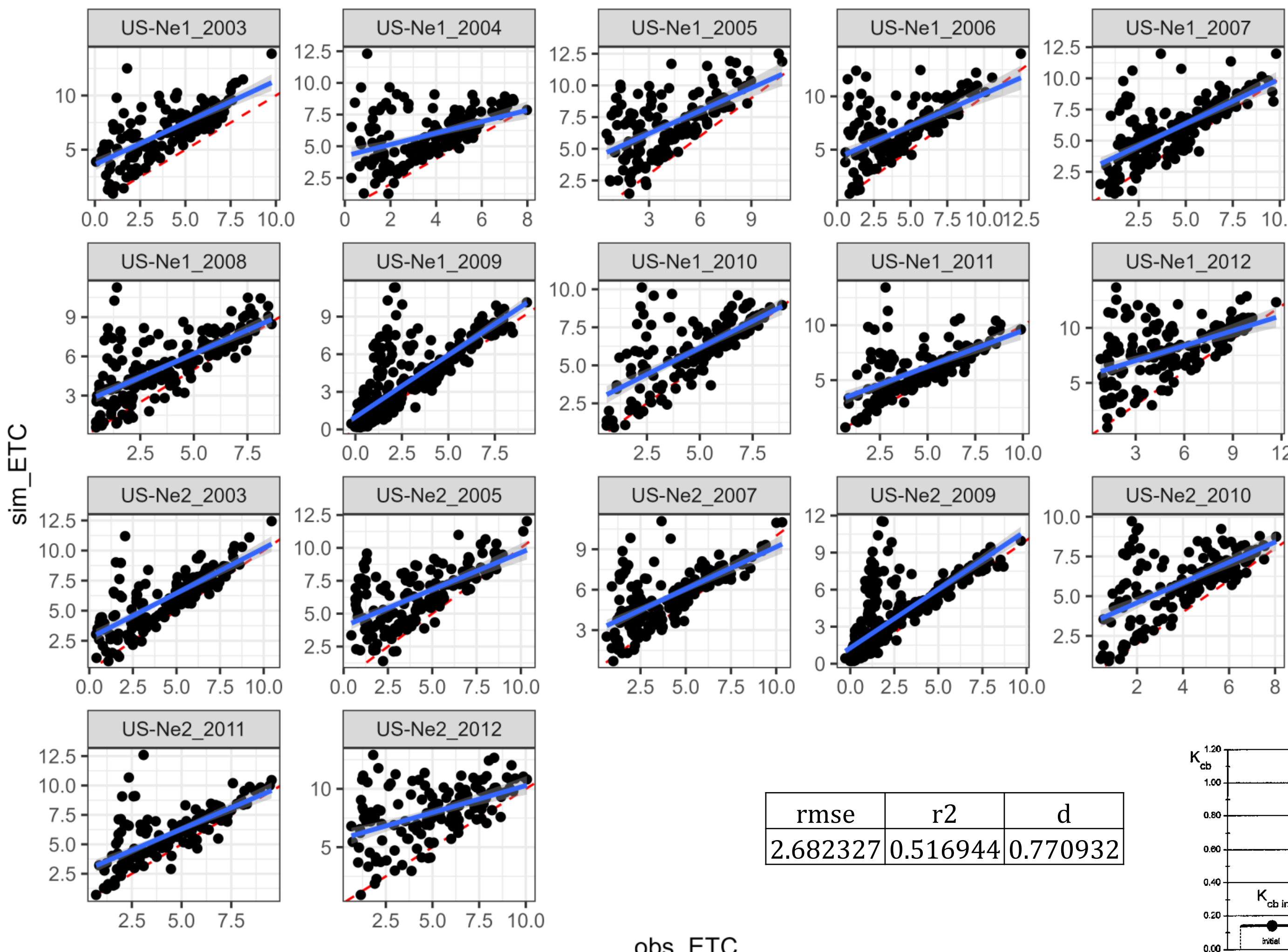
Performance (Default)



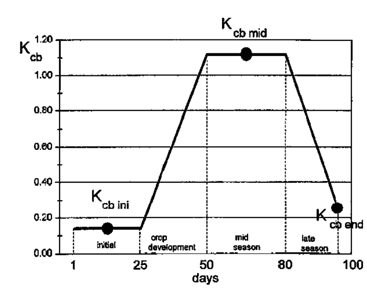
rmse	r2	d
2.560792	0.343478	0.738828



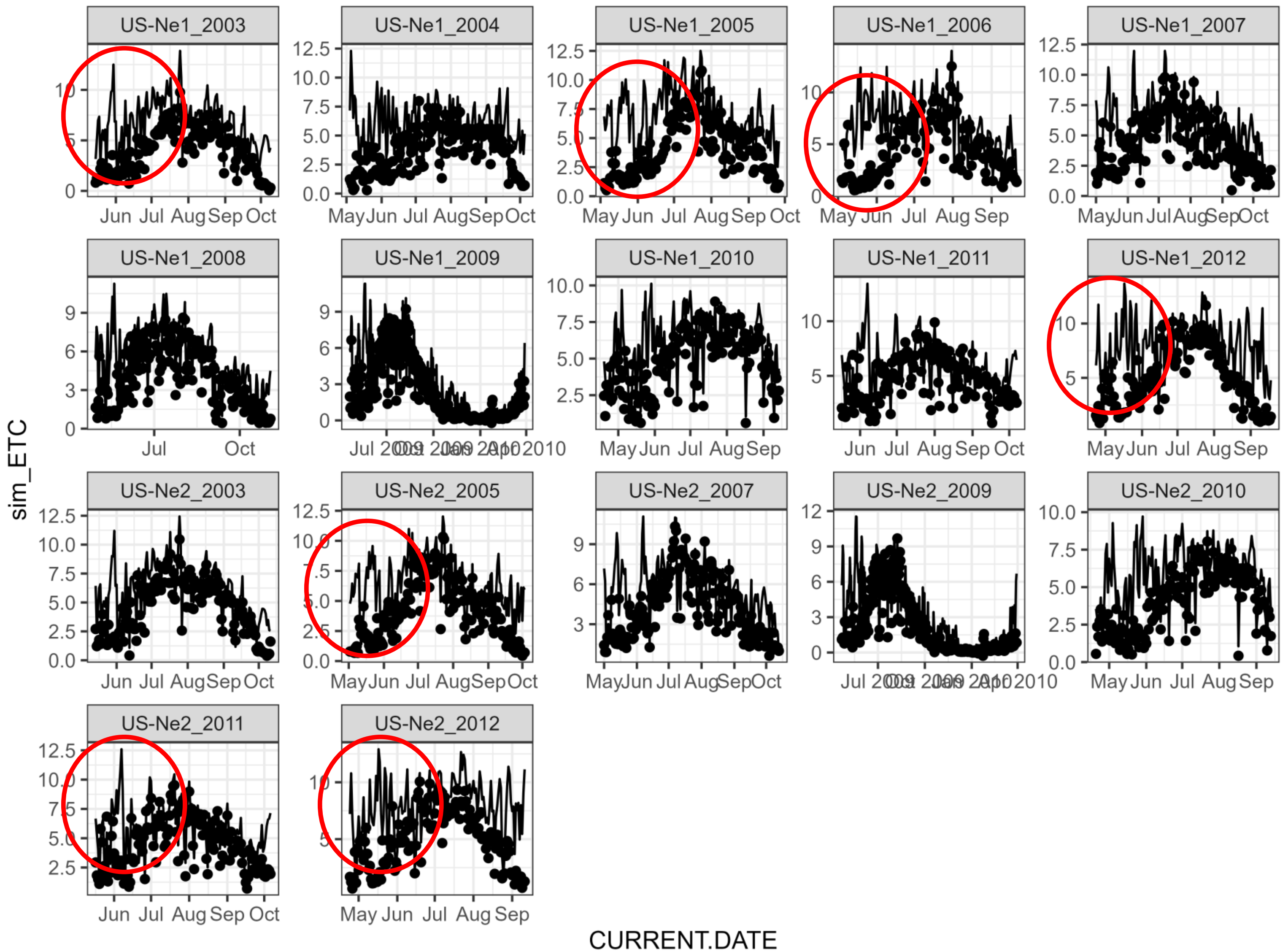
Performance (Calibrated)



rmse	r2	d
2.682327	0.516944	0.770932



Performance (Calibrated)



Caveats

- Definition of ETc and the reduction coefficients (iK_s and iK_r)

- Correction for characteristic RH_min, u2 and h

- Ritchie equation relating Kcb ~ LAI

Definition of ETc and the reduction coefficients (iK_s and iK_r)

- This SimComponent was initialy implemented to simulate potential rates.

- iK_r and iK_s are to scale the potential rates of soil evaporation and transpiration

- Evapotranspiration definitions:
  - ETC: “Crop evapotranspiration under standard conditions" (Allen et al., 1998)
    - ETC = Actual Soil Evaporation + Potential Crop Transpiration
  - ETP: Pontential evapotranspiration
    - ETP = Potential Soil Evaporation + Potential Crop Transpiration

iK_r ≤ *1*
iK_s = *1*

iK_r = *1*
iK_s = *1*

To compare measured ETC with simulated ETC a waterbalance must be coupled to provide ***iK_r* ≤ *1***

Component Variables

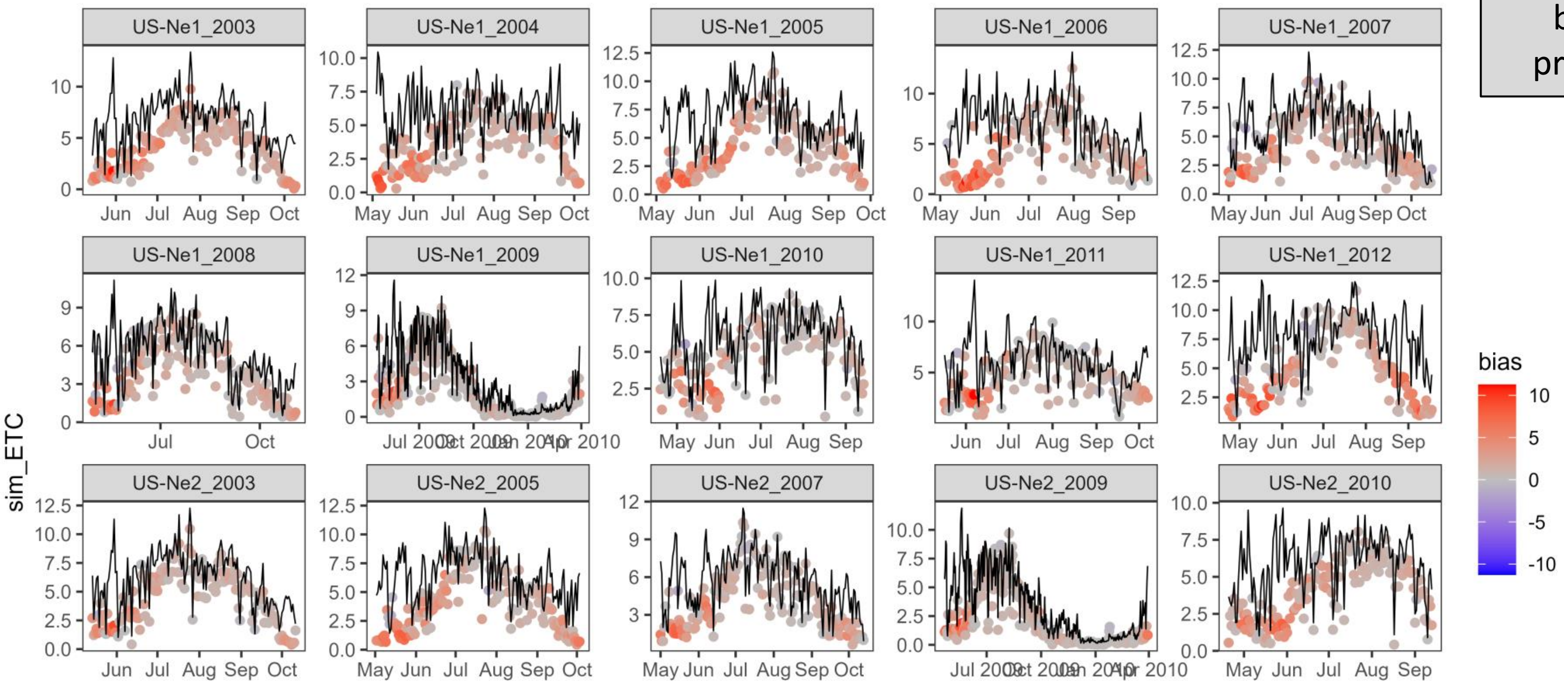
out	ETC	crop ET under standard conditions (no water, nutrient, weed, pest or disease limitations to growth)

Definition of ETc and the reduction coefficients (iK_s and iK_r)

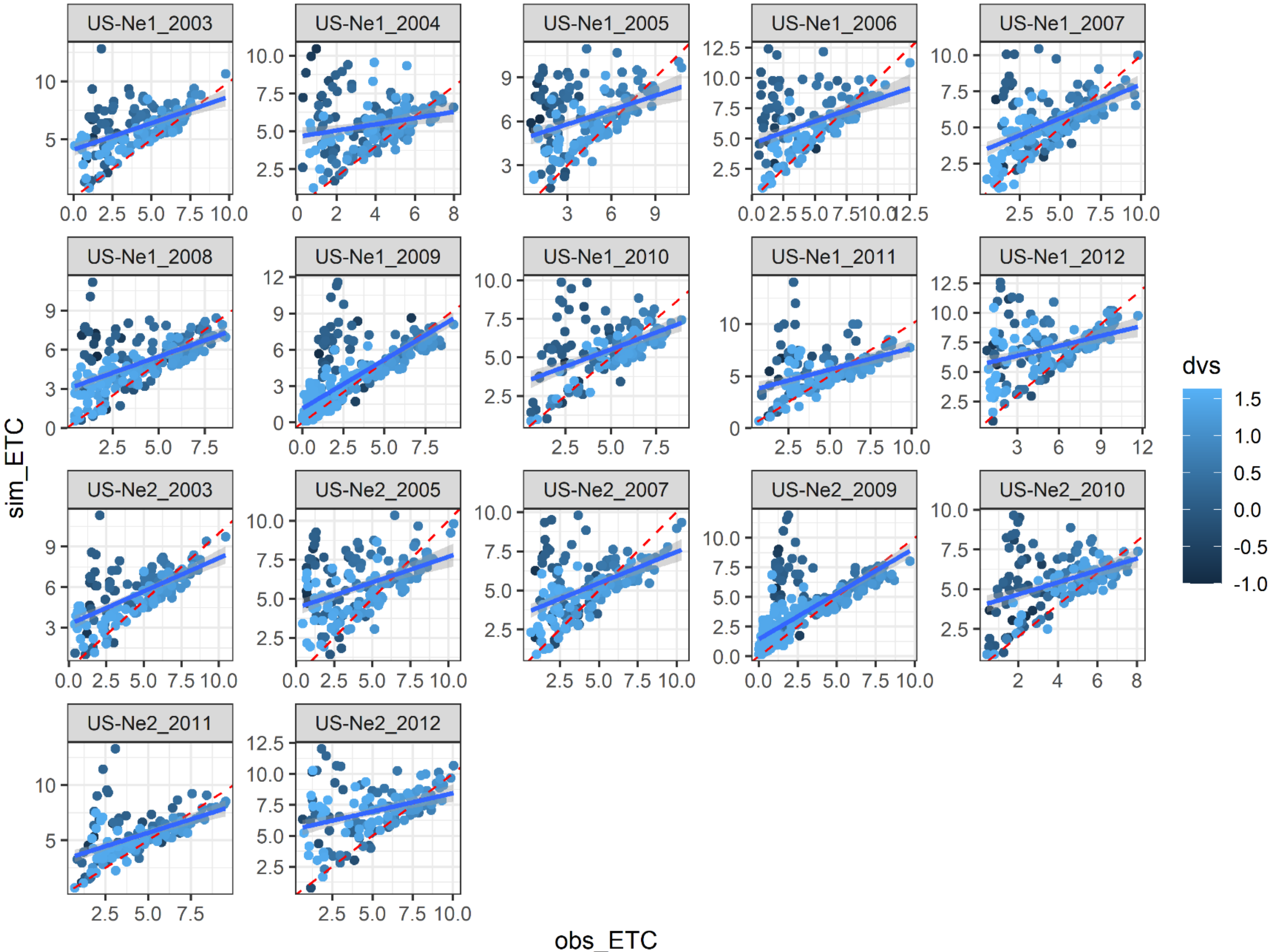
- Evapotranspiration definitions:
  - ETC: Crop evapotranspiration under standard conditions (Allen et al., 1998)
    - ETC = Actual Soil Evaporation + Potential Crop Transpiration
  - ETP: Potential evapotranspiration
    - ETP = Potential Soil Evaporation + Potential Crop Transpiration

iK_r ≤ 1
iK_s = 1

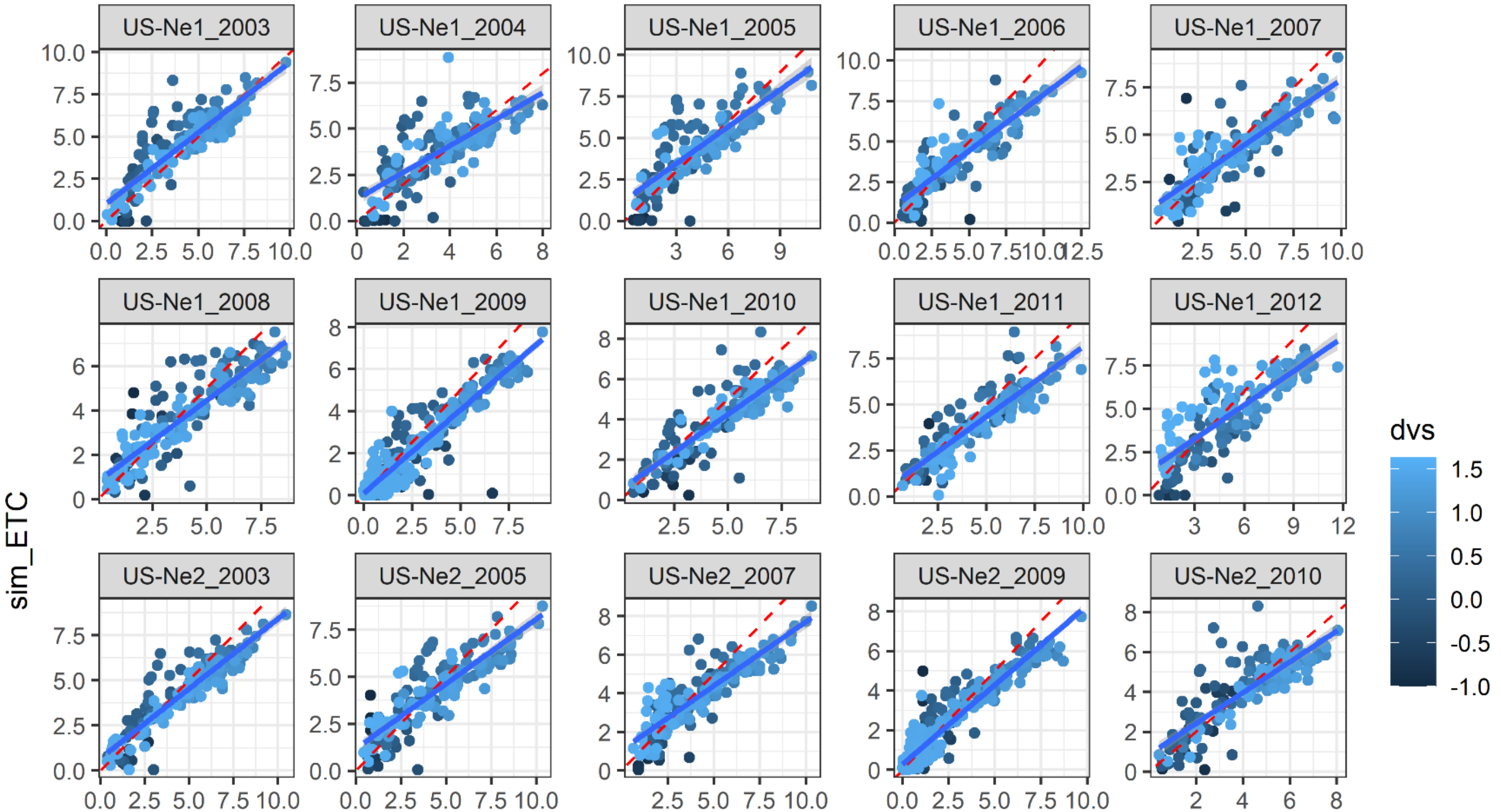
To compare measured ETC with simulated ETC a waterbalance must be coupled to provide ***iK_r ≤ 1***

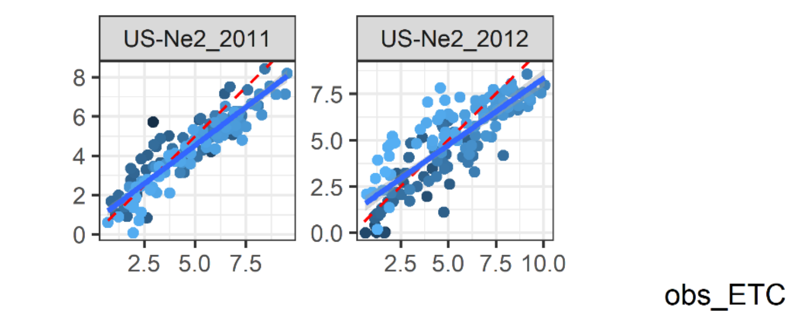


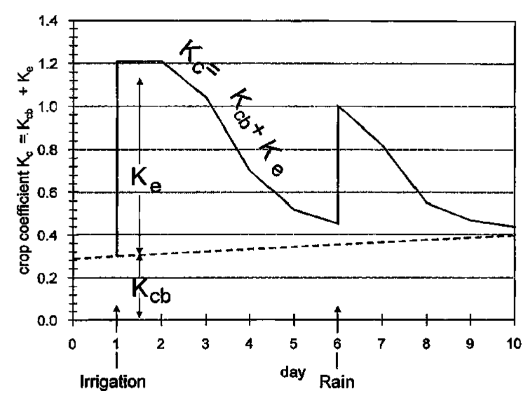
No topsoil water balance (Kr = 1)

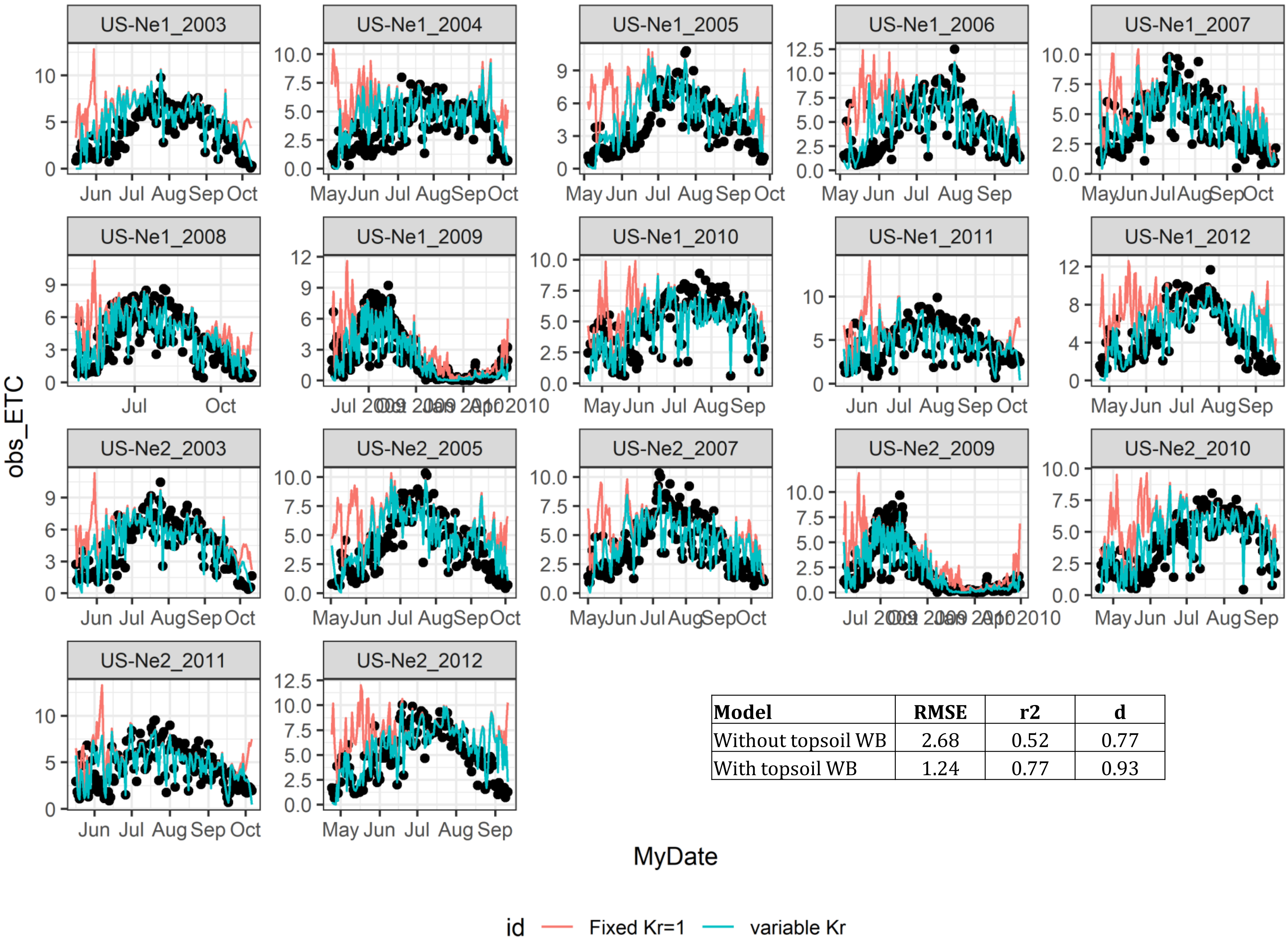


With topsoil water balance (variable Kr)









Model	RMSE	r2	d
Without topsoil WB	2.68	0.52	0.77
With topsoil WB	1.24	0.77	0.93

Correction for characteristic RH_min, u2 and h

- Kcmax = 1.2 + (0.04*(u2-2) - 0.004*(RH_min - 45))*(h/3)^0.3
- KcbFull = cKcbMid + (0.04*(u2-2) – 0.004*(RH_min – 45))*(h/3)^0.3

$$K_{cb} = K_{cb(Tab)} + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3} \quad (70)$$

where

$K_{cb\ (Tab)}$ the value for $K_{cb\ mid}$ or $K_{cb\ end}$ (if ≥ 0.45) taken from Table 17,

u_2 the mean value for daily wind speed at 2 m height over grass during the mid or late season growth stage [m s^{-1}] for 1 m s^{-1} ≤ u_2 ≤ 6 m s^{-1},

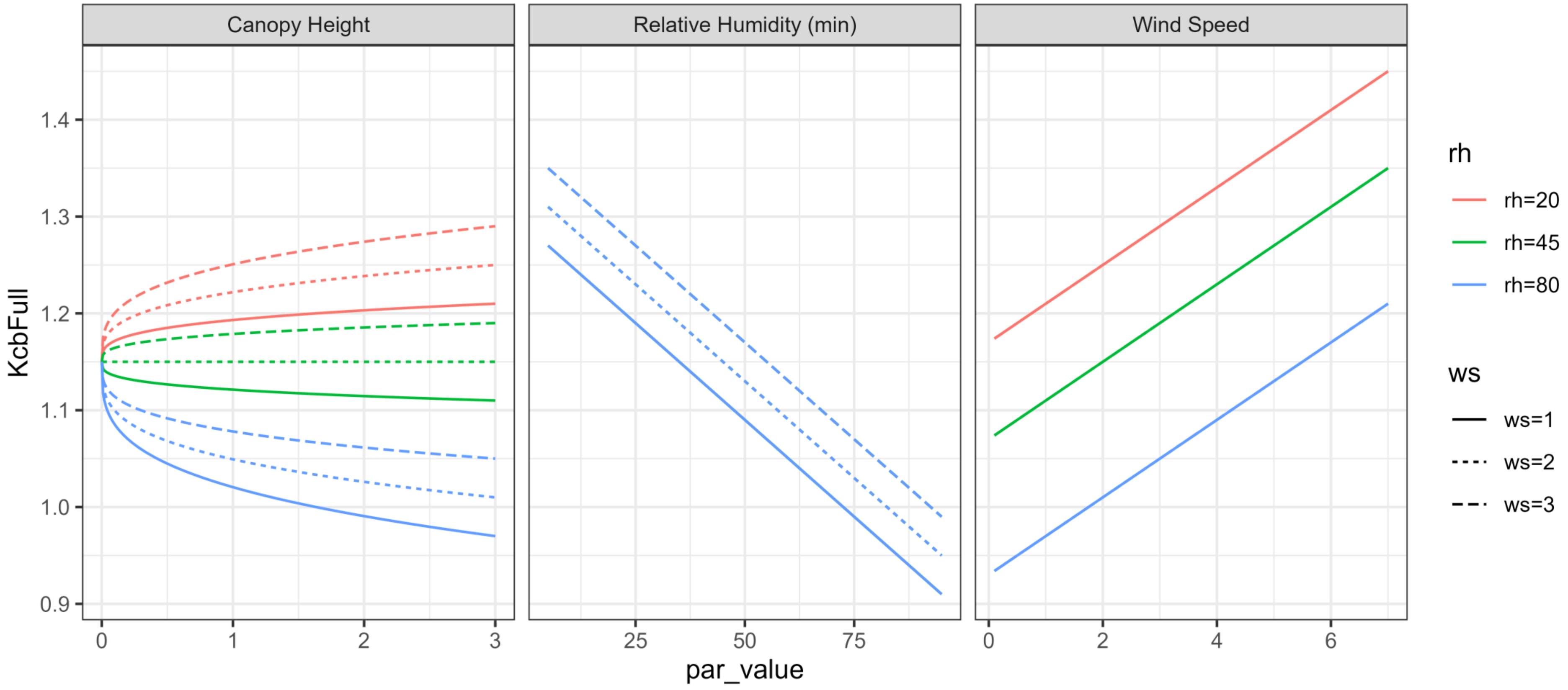
RH_{min} the mean value for daily minimum relative humidity during the mid- or late season growth stage [%] for 20% ≤ RH_{min} ≤ 80%,

h the mean plant height during the mid or late season stage [m] (from Table 12) for 20% ≤ RH_{min} ≤ 80%.

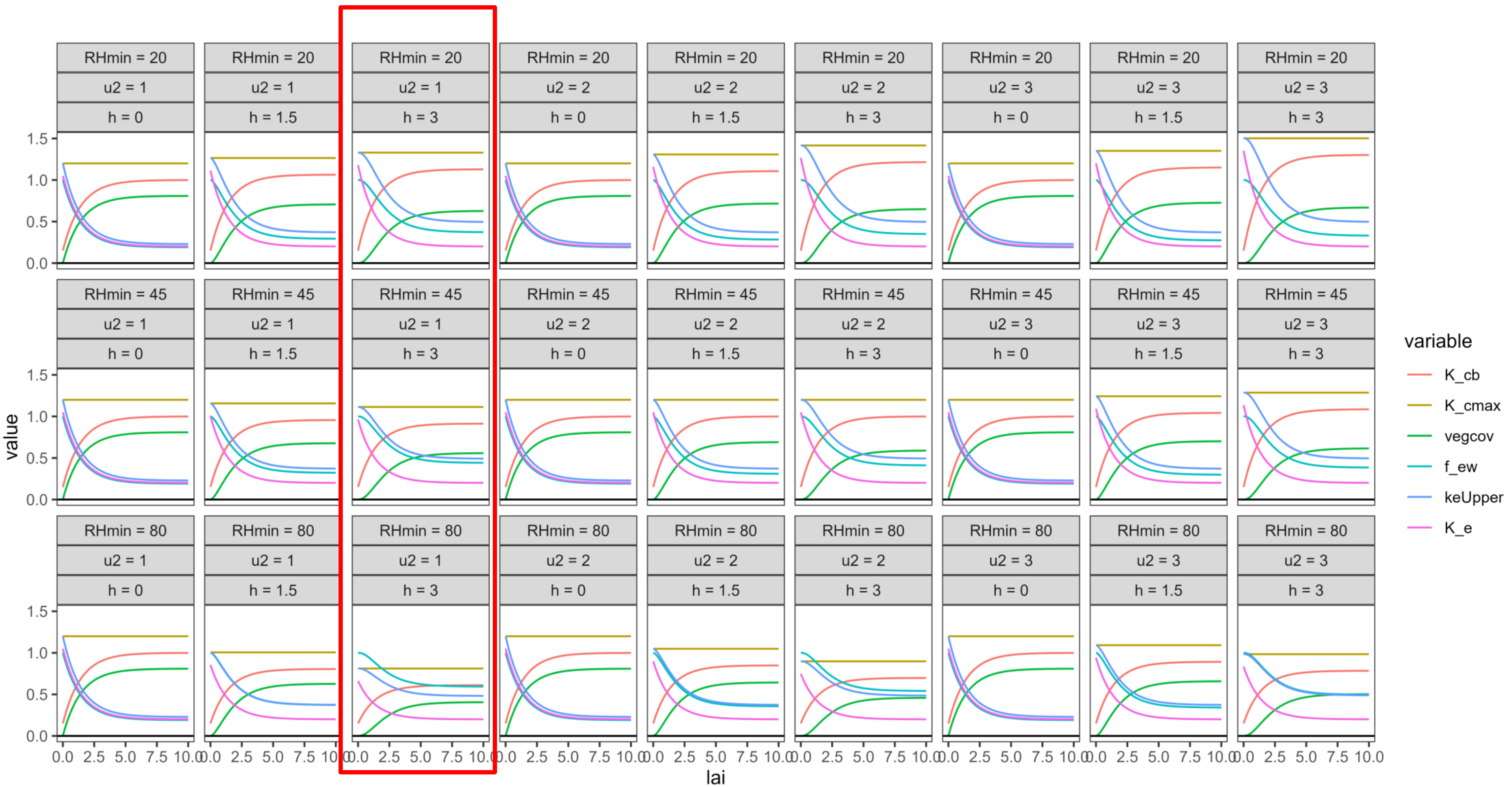
- How to convert the crop model development scale into the FAO-development scale (ini, dev, mid, late)?
- How these correction affect the dynamics of ET? Can we trust when this correction is performed for out-of-bounds conditions?
- If modelers inform measured Kc or Kcb value it may already represent the environmental characteristic of the source site.

Sensitivity of KcbFull

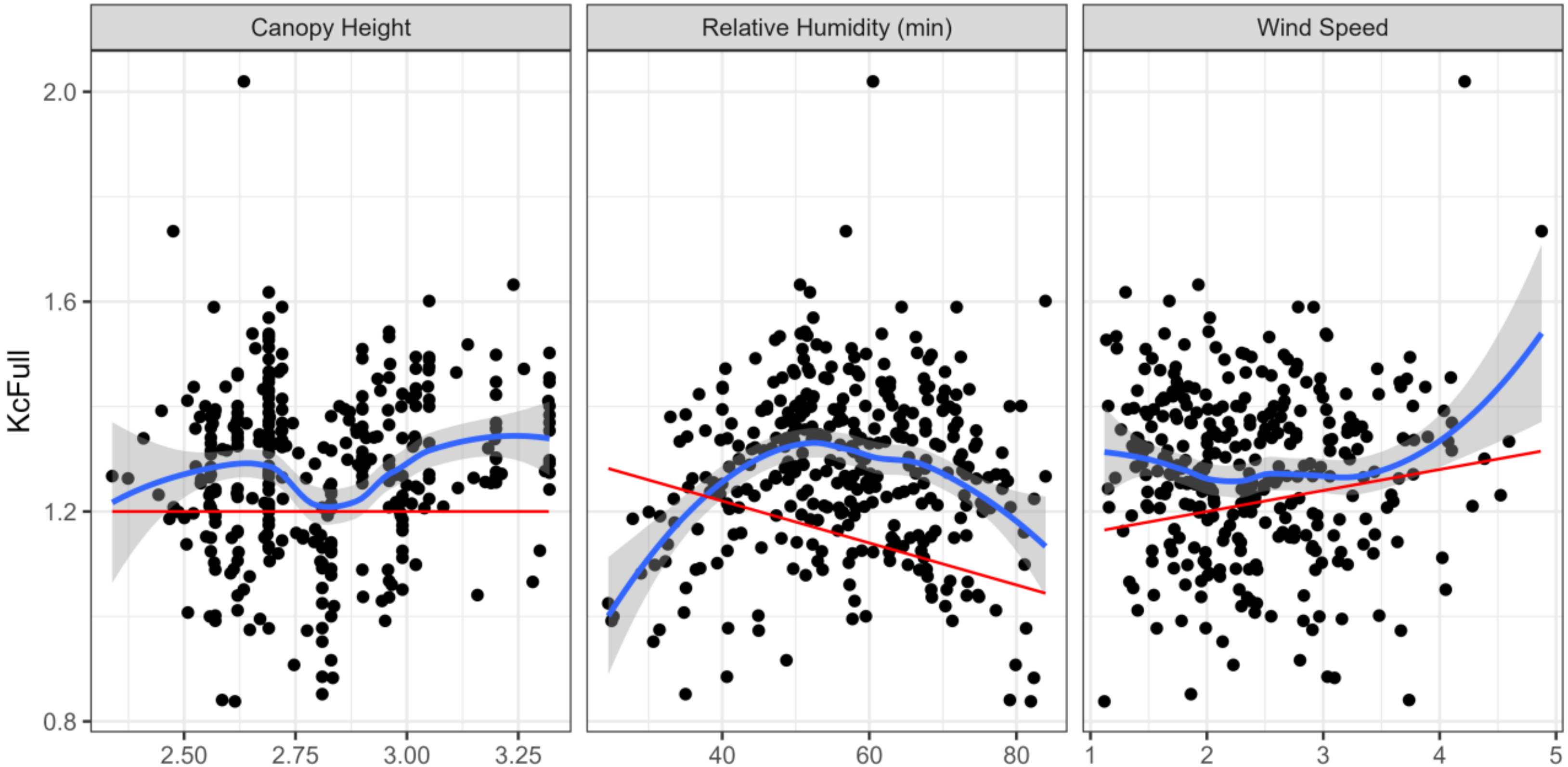
KcbFull = cKcbMid + (0.04*(u2-2) – 0.004*(RH_min – 45))*(h/3)^0.3



Sensitivity of other variables

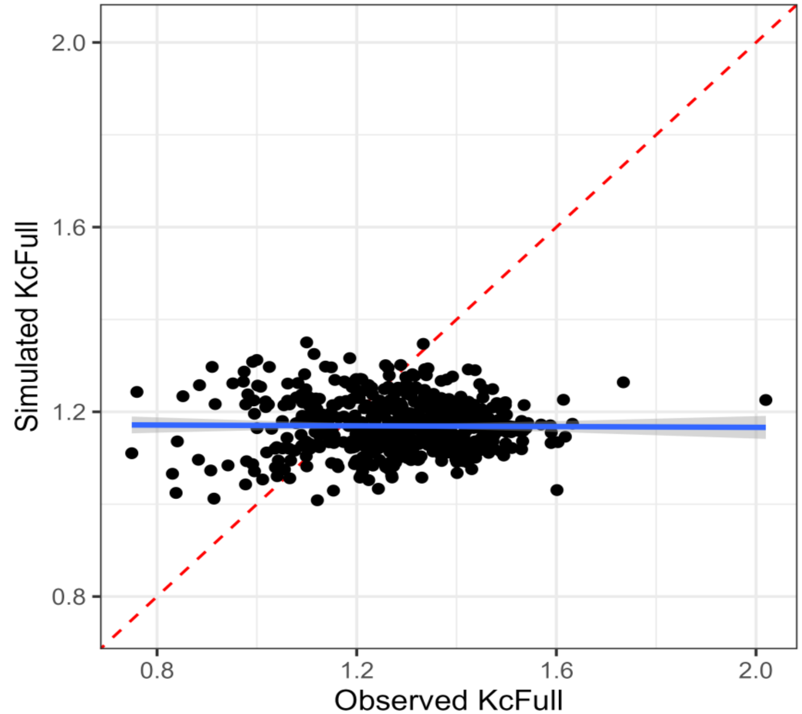


Testing it against field data



- KcFull = ETc/ETo when LAI > 0.95*max(LAI)

Testing it against field data



- Use this corrections with caution as it may increase model complexity without gaining performance (keep the default values)
- When Kc are calibrated or obtained from field experiment, this corrections may not be necessary

Theor Appl Climatol (2013) 114:495–510
DOI 10.1007/s00704-013-0848-6

ORIGINAL PAPER

Single and dual crop coefficients and crop evapotranspiration for wheat and maize in a semi-arid region

M. H. Shahrokhnia · A. R. Sepaskhah

Adapted equation →

$$\text{Maize}: \ K_{cb-mid} = K_{cb-mid(table)} + [0.04(u_2 - 2) - 0.009(RH_{min} - 45)]\left[\frac{h}{3}\right]^{0.3}$$

Kcb ~ LAI

Chapter 9 - ET_c for natural, non-typical and non-pristine vegetation

$$K_{cb\ mid} = K_{c\ min} + (K_{cb\ full} - K_{c\ min})(1 - \exp[-0.7\ LAI])\ (97)$$

Implementing Standardized Reference Evapotranspiration and Dual Crop Coefficient Approach in the DSSAT Cropping System Model

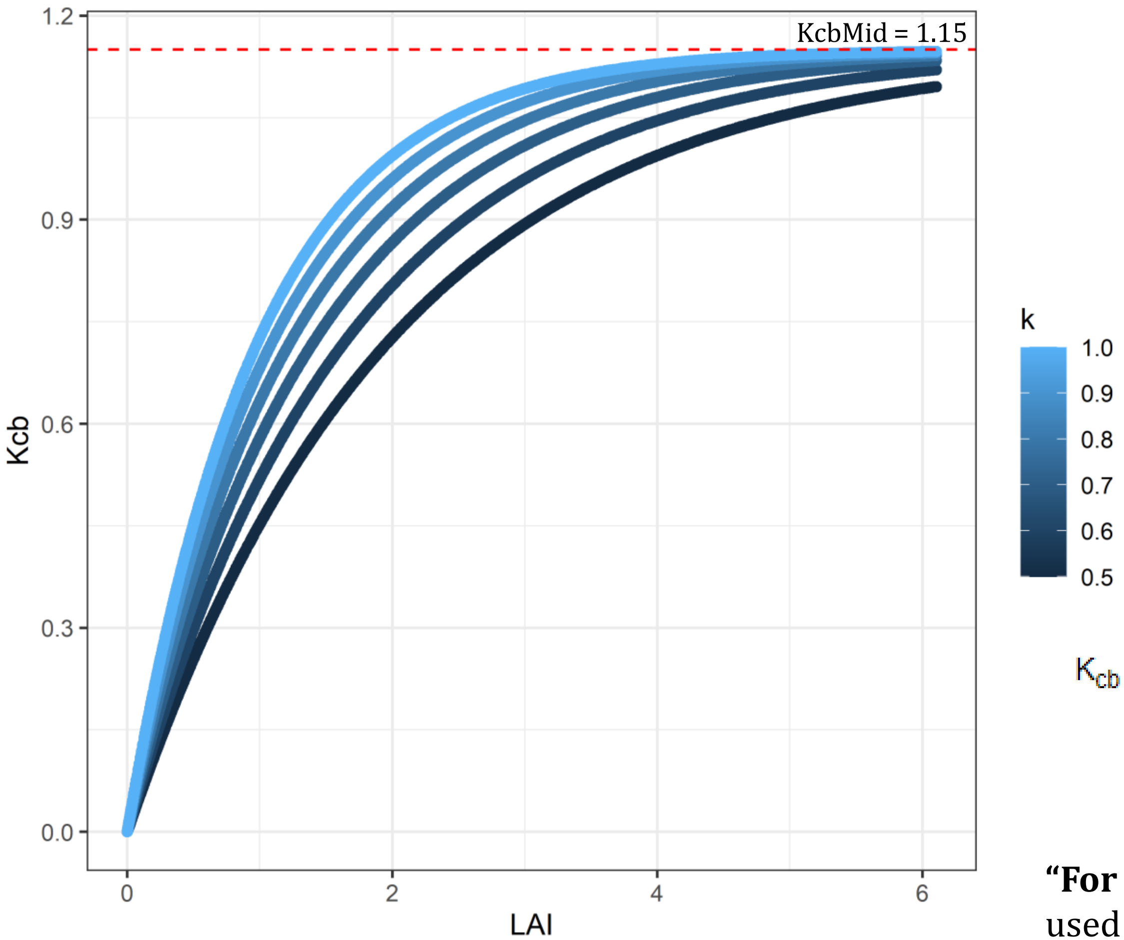
K. C. DeJonge, K. R. Thorp

Published in *Transactions of the ASABE* 60(6): 1965-1981 (doi: 10.13031/trans.12321). 2017 American Society of Agricultural and Biological Engineers.

$$K_{cb} = K_{cbmin} + (K_{cbmax} - K_{cbmin})(1 - \exp[-SK_c(\mathrm{LAI})])\ (6)$$

- Explicitly separate crop transpiration and soil evaporation
- More flexible as k is no longer hardwired (0.7)

Kcb ~ LAI



LAI	k	Kcb
6.1	0.50	1.0957
6.1	0.60	1.1205
6.1	0.70	1.1340
6.1	0.80	1.1413
6.1	0.90	1.1453
6.1	1.00	1.1474

$$K_{cb\ mid} = K_{c\ min} + (K_{cb\ full} - K_{c\ min})(1 - \exp[-0.7\ LAI]) \quad (97)$$

"For LAI > 3, Kcb mid ~ Kcb full. The LAI used in Equation 97 should be the 'green' LAI representing only healthy leaves that are active in vapour transfer." (Allen et al., 1998)

Updates

SimComponent modifications:

- cKcbIni instead of KcIni in equation relating Kcb ~ LAI (Avoid T when LAI =0 & explicitly separate T and E)

- The harwired "0.7" converted to a user-specific parameter (cK) (+ Flexibility and consistency with light interception dynamics)

Bugfixes:

- (Kcb – Kcmin) constrained to 0 for numerical stability (Avoid NaN at early stages)

Updated Documentation

- Updated wiki (https://simplace.net/doc/simplace_modules/), document file + this ppt in simplace_doc (SVN)

Thank you!

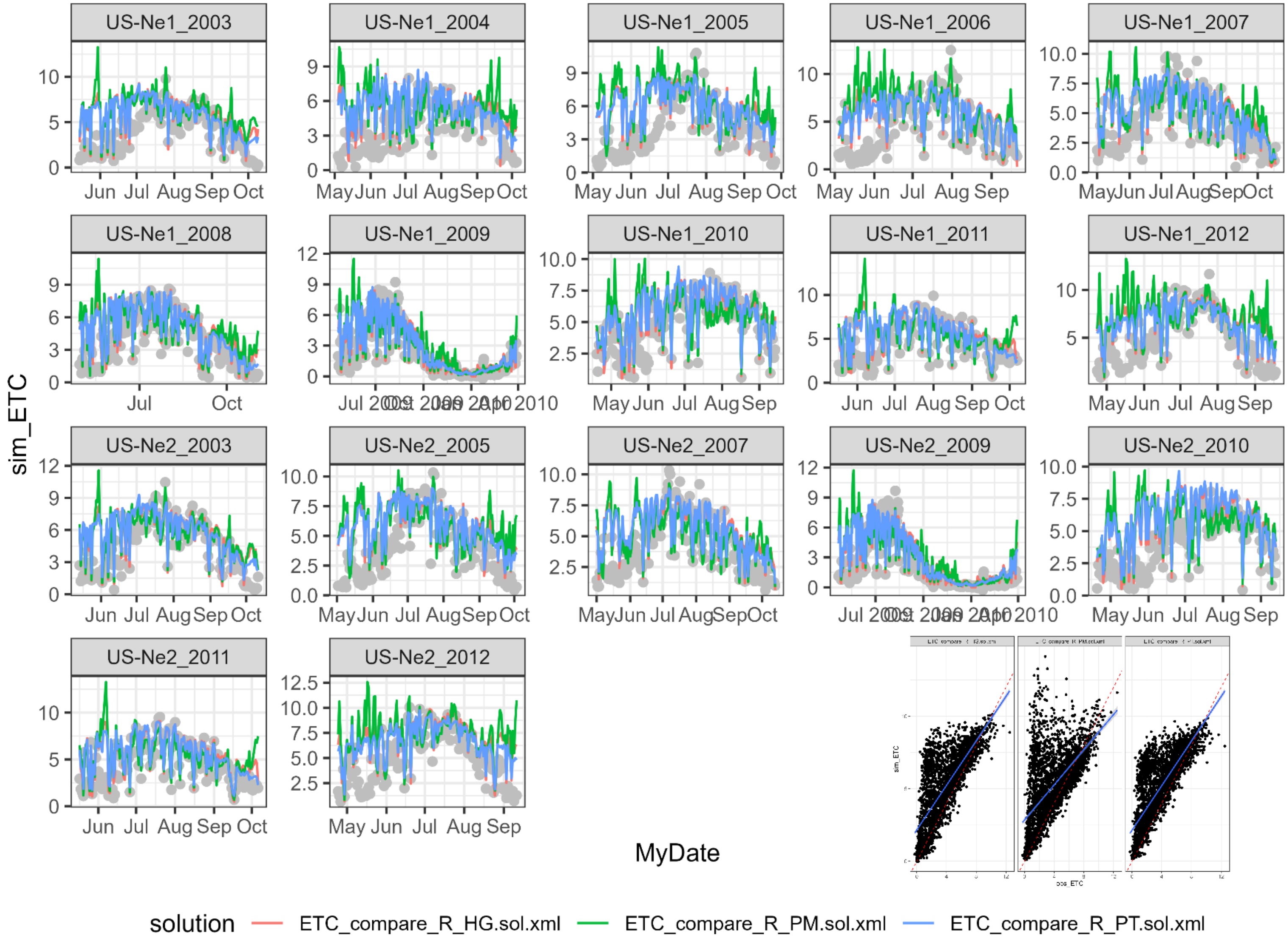
LAP Colloquium

Murilo Vianna

Mar-2022

Extra Slides

Different ETo



SimComponent Outputs

out	ActualTranspiration	adjusted rate of transpiration from the soil under - when K_s is set -water stress conditions	DOUBLE	mm/d	0.0	20.0	-
out	ETC	crop ET under standard conditions (no water, nutrient, weed, pest or disease limitations to growth)	DOUBLE	mm/d	0.0	20.0	-
out	ETCUpper	upper limit (no evaporation reduction K_r) of crop ET under standard (or - when K_s is set - water stress) conditions (no nutrient, weed, pest or disease limitations to growth)	DOUBLE	mm/d	0.0	20.0	-
out	ETC_adj	adjusted crop ET under - when K_s is set - water stress conditions (no water, nutrient, weed, pest or disease limitations to growth???)	DOUBLE	mm/d	0.0	20.0	-
out	KcMax	Upper limit on ETC	DOUBLE	1	0.0	2.0	1.0
out	Kcb	basal crop coefficient	DOUBLE	1	0.0	2.0	-
out	Ke	soil evaporation coefficient	DOUBLE	1	0.0	2.0	-
out	KeUpper	upper limit of soil evaporation coefficient (no evaporation reduction K_r)	DOUBLE	1	0.0	2.0	-
out	PotentialSoilEvapCrop	Potential rate of evaporation from the soil	DOUBLE	mm/d	0.0	20.0	-
out	PotentialSoilEvapCropUpper	Upper limit (no evaporation reduction K_r) of potential rate of evaporation from the soil	DOUBLE	mm/d	0.0	20.0	-
out	PotentialTranspiration	Potential rate of transpiration from the crop	DOUBLE	mm/d	0.0	20.0	-

Theoretical and Applied Climatology (2019) 138:1785–1793
https://doi.org/10.1007/s00704-019-02940-7

ORIGINAL PAPER

Check for updates

Revisiting the crop coefficient–reference evapotranspiration procedure for improving irrigation management

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Crop coefficient changes with reference evapotranspiration for highly canopy-atmosphere coupled crops

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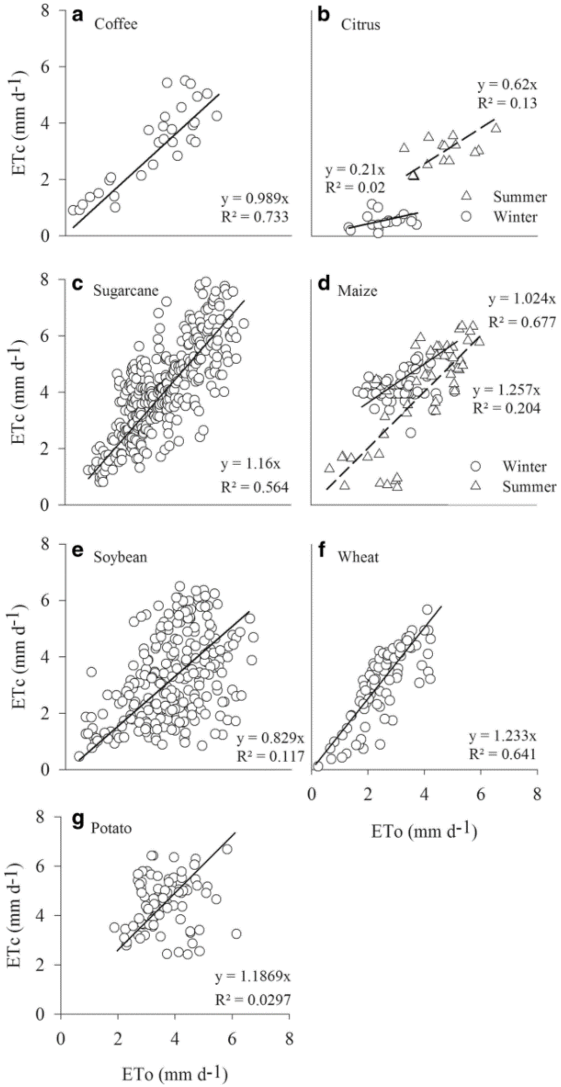

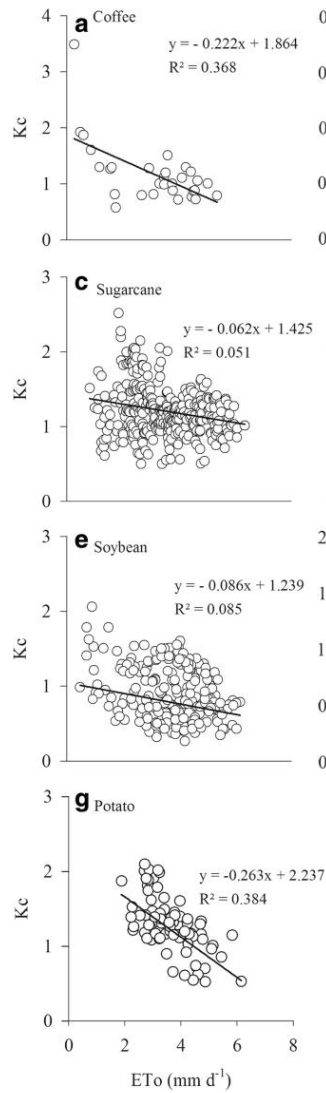

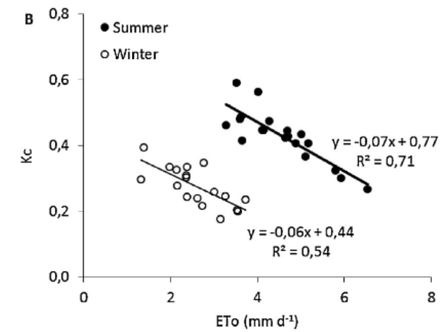

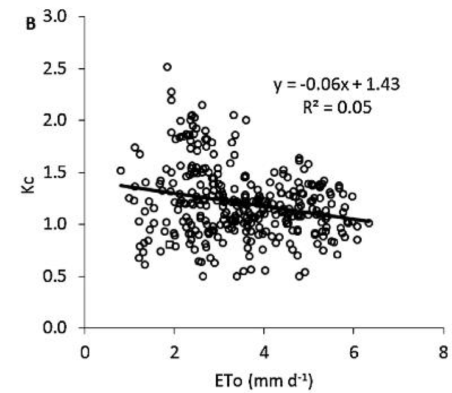

$$\Omega = \frac{1}{1 + \left[\frac{2r_s}{\left(\frac{s}{\gamma}+2\right)r_a}\right]}$$

Ritchie equation

Estimation of $K_{cb\ mid}$ from Leaf Area Index (LAI)

Natural vegetation typically has less leaf area or fraction of ground cover than does agricultural vegetation that has been developed for full ground cover and for soil water conditions favouring vigorous growth. This is especially true in semi-arid and arid climates. The value for $K_{cb\ mid}$ for natural or non-pristine vegetation should be reduced when plant density and/or leaf area are lower than for full cover conditions (generally defined as when LAI $\geq$ 3). Where LAI can be measured or approximated, a peak $K_{cb\ mid}$ for natural, non-typical or non-pristine agricultural vegetation can be approximated similar to a procedure used by Ritchie as:

$$K_{cb\ mid} = K_{c\ min} + (K_{cb\ full} - K_{c\ min})(1 - \exp[-0.7\ LAI]) \quad (97)$$

where

$K_{cb\ mid}$ estimated basal K_{cb} during the mid-season when plant density and/or leaf area are lower than for full cover conditions,

$K_{cb\ full}$ estimated basal K_{cb} during the mid-season (at peak plant size or height) for vegetation having full ground cover or LAI > 3 (Equations 99 and 100),

$K_{c\ min}$ the minimum K_c for bare soil ($K_{c\ min} \approx 0.15 - 0.20$),

LAI actual leaf area index, defined as the area of leaves per area of underlying ground surface averaged over a large area. Only one side of leaves is counted [$m^2\ m^{-2}$].

Equation 97 is recommended for annual types of vegetation that are either natural or are in a non-pristine state due to sparse density or effects of some type of environmental stress on growth.

The relationship expressed in Equation 97 produces results similar to those suggested by Ritchie (1974). For LAI > 3, $K_{cb\ mid} \approx K_{cb\ full}$. The LAI used in Equation 97 should be the 'green' LAI representing only healthy leaves that are active in vapour transfer.

Kcb ~ LAI

Soil evaporation coefficient (Ke)

$$K_e = K_r\,(K_{c\,max} - K_{cb}) \le f_{ew}\,K_{c\,max}$$

Soil Water Balance

Atmospheric Correction

$$K_{cmax} = \max\left(\left\{1.2 + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3}\right\}, \left\{K_{cb} + 0.05\right\}\right)$$

$$f_{ew} = \min(1 - f_c, f_w)$$

$$f_c = \left(\frac{K_{cb} - K_{cmin}}{K_{cmax} - K_{cmin}}\right)^{(1+0.5h)}$$

Crop transpiration (Kcb)

$$K_{cb} = K_{cbmin} + (K_{cbmax} - K_{cbmin})(1 - \exp[-SK_c(LAI)]) \quad (6)$$

- Difficult to understand the dependency between fc and Kcb
- It becomes even more complex if canopy height is not default (h=0) due to term ^(1+0.5*h) used to determine fc
- This reinforces the recommendation of keeping the default values of cCharacteristicMeanRelHumidity, cCharacteristicWindspeed, **cCropHeight**.